NEBULÆ.

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(Read April 13, 1917.)

In addition to the planets and comets of our solar system and the countless stars of our stellar system there appear on the sky many cloud-like masses—the nebulæ. These for a long time have been generally regarded as presenting an early stage in the evolution of the stars and of our solar system, and they have been carefully studied and something like 10,000 of them catalogued.

Keeler's classical investigation of the nebulæ with the Crossley reflector by photographic means revealed unknown nebulæ in great numbers. He estimated that such plates as his if they were made to cover the whole sky would contain at least 120,000 nebulæ, an estimate which later observations show to be considerably too small. He made also the surprising discovery that more than half of all nebulæ are spiral in form; and he expressed the opinion that the spiral nebulæ might prove to be of particular interest in questions concerning cosmogony.

I wish to give at this time a brief account of a spectrographic investigation of the spiral nebulæ which I have been conducting at the Lowell Observatory since 1912. Observations had been previously made, notably by Fath at the Lick and Mount Wilson Observatories, which yielded valuable information on the character of the spectra of the spiral nebulæ. These objects have since been found to be possessed of extraordinary motions and it is the observation of these that will be discussed here.

In their general features nebular spectra may for convenience be placed under two types characterized as (I.) bright-line and (II.) dark-line. The gaseous nebulæ, which include the planetary and some of the irregular nebulæ, are of the first type; while the much more numerous family of spiral nebulæ are, in the main, of the second type. But the two are not mutually exclusive and in the

spirals are sometimes found both types of spectra. This is true of the nebulæ numbered 598, 1068 and 5236 of the "New General Catalogue" of nebulæ.

Some of the gaseous nebulæ are relatively bright and their spectra are especially so since their light is all concentrated in a few bright spectral lines. These have been successfully observed for a long time. Keeler in his well-known determination of the velocities of thirteen gaseous nebulæ was able to employ visually more than twenty times the dispersion usable on the spiral nebulæ.

Spiral nebulæ are intrinsically very faint. The amount of their light admitted by the narrow slit of the spectrograph is only a small fraction of the whole and when it is dispersed by the prism it forms a continuous spectrum of extreme weakness. The faintness of these spectra has discouraged their investigation until recent years. It will be only emphasizing the fact that their faintness still imposes a very serious obstacle to their spectrographic study when it is pointed out, for example, that an excellent spectrogram of the Virgo spiral N.G.C. 4594 secured with the great Mount Wilson reflector by Pease was exposed eighty hours.

A large telescope has some advantages in this work, but unfortunately no choice of telescope either of aperture or focal-length will increase the brightness of the nebular surface. It is chiefly influenced by the spectrograph whose camera alone practically determines the efficiency of the whole equipment. The camera of the Lowell spectrograph has a lens working at a speed ratio of about 1 : 2.5. The dispersion piece of the spectrograph has generally been a 64° prism of dense glass, but for two of the nebulæ a dispersion of two 64° prisms was used. The spectrograph was attached to the 24-inch refractor.

With this equipment I have secured between forty and fifty spectrograms of 25 spiral nebulæ. The exposures are long—generally from twenty to forty hours. It is usual to continue the exposure through several nights but occasionally it may run into weeks owing to unfavorable weather or the telescope's use in other work. Besides the exposures cannot be continued in the presence of bright moonlight and this seriously retards the accumulation of observations.

The iron-vanadium spark comparison spectrum is exposed a number of times during the nebular exposure in order to insure that the comparison lines are subjected to the same influences as the nebular lines. The spectrograph is electrically maintained at a constant temperature which avoids the ill effects of the usual fall of the night temperature.

The equivalent slit-width is usually about .06 mm.

The linear dispersion of the spectra is about 140 tenth-meters per millimeter in the violet of the spectrum which is sufficient to detect and measure the velocities of the spiral nebulæ. As the objects yet to be observed are fainter than those already observed the prospects of increasing the accuracy by employing greater dispersion are not now promising.

The plates are measured under the Hartmann spectrocomparator in which one optically superposes the nebular plate of unknown velocity upon one of a like dark-line spectrum of known velocity, used as standard. A micrometer screw, which shifts one plate relatively to the other, is read when the dark lines of the nebula and the standard spectrum coincide; and again when the comparison lines of the two plates coincide. The difference of the two screw readings with the known dispersion of the spectrum gives the velocity of the nebula. By this method weak lines and groups of lines can be utilized that otherwise would not be available because of faintness or uncertainty of wave-length.

TABLE I.

RADIAL VELOCITIES OF TWENTY-FIVE SPIRAL NEBULÆ.

Nebula.	Vel.	Nebula.	Vel.
N.G.C. 221	− 300 km.	N.G.C. 4526	+ 580 km.
224	− 300	4565	+1100
598	− 260	4594	+1100
1023	+ 300	4649	+1090
1068	+1100	4736	+ 290
2683	+ 400	4826	+ 150
3031	− 30	5005	+ 900
3115	+ 600	5055	+ 450
3379	+ 780	5194	+ 270
3521	+ 730	5236	+ 500
3623	+ 800	5866	+ 650
3627	+ 650	7331	+ 500
4258	+ 500		

In Table I. are given the velocities for the twenty-five spiral nebulæ thus far observed. In the first column is the New General Catalogue number of the nebula and in the second the velocity. The plus sign denotes the nebula is receding, the minus sign that it is approaching.

Generally the value of the velocity depends upon a single plate which, in many instances, was underexposed and some of the values for these reasons may be in error by as much as 100 kilometers. This however is not so discreditable as at first it might seem to be. The arithmetic mean of the velocities is 570 km. and 100 km. is hence scarcely 20 per cent. of the quantity observed. With stars the average velocity is about 20 km. and two observers with different instruments and a single observation each of an average star might differ in its velocity by 20 per cent. of the quantity measured. Thus owing to the very high magnitude of the velocity of the spiral nebulæ the percentage error in its observation is comparable with that of star velocity measures.

Since the earlier publication of my preliminary velocities for a part of this list of spiral nebulæ, observations have been made elsewhere of four objects with results in fair agreement with mine, as shown in Table II.

TABLE II.

VELOCITIES OF NEBULÆ BY DIFFERENT OBSERVERS.

Nebulæ.	Velocity.	Observers.
N.G.C. 224	— 300 km.	Slipher, mean from several plates.
Great Andromeda	— 304	Wright, Lick Observatory, one plate.
Nebula.	— 329	Pease, Mt. Wilson Observatory, one plate.
	— 300 to 400 km.	Wolf, Heidelberg, one plate approx.
N.G.C. 598	— 278	Pease, Mt. Wilson, from bright lines.
Great Spiral of Triangulum.	— 263	Slipher, from bright lines.
N.G.C. 1068	+ 1100	Slipher, from dark and bright lines.
	+ 765	Pease, from two bright lines.
	+ 910	Moore, Lick Observatory, from three bright lines.
N.G.C. 4594	+ 1100	Slipher.
	+ 1180 km.	Pease, Mt. Wilson Observatory.

Referring to the table of velocities again: the average velocity 570 km. is about thirty times the average velocity of the stars. And it is so much greater than that known of any other class of celestial bodies as to set the spiral nebulæ aside in a class to themselves. Their distribution over the sky likewise shows them to be unique—they shun the Milky Way and cluster about its poles.

The mean of the velocities with regard to sign is positive, implying the nebulæ are receding with a velocity of nearly 500 km. This might suggest that the spiral nebulæ are scattering but their distribution on the sky is not in accord with this since they are inclined to cluster. A little later a tentative explanation of the preponderance of positive velocities will be suggested.

Grouping the nebulæ as in Table III., there appears to be some evidence that spiral nebulæ move edge forward.

TABLE III.

VELOCITIES OF SPIRAL NEBULÆ GROUPED.

Face View Spirals.		Inclined Spirals.		Edge View Spirals.	
N.G.C.	Vel.	N.G.C.	Vel.	N.G.C.	Vel.
598	− 260 km.	224	− 300 km.	2683	+ 400 km.
4736	+ 290	3623	+ 800	3115	+ 600
5194	+ 270	3627	+ 650	4565	+ 1100
5236	+ 500	4826	+ 300	4594	+ 1100
		5005	+ 920	5866	+ 600
		5055	+ 450		
		7331	+ 500		
Mean.....	330 km.	....	560 km.	....	760 km.

The form of the spiral nebulæ strongly suggests rotational motion. In the spring of 1913 I obtained spectrograms of the spiral nebulæ N.G.C. 4594 the lines of which were inclined after the manner of those in the spectrum of Jupiter, and, later, spectrograms which showed rotation or internal motion in the Great Andromeda Nebula and in the two in Leo N.G.C. 3623 and 3627 and in nebulæ N.G.C. 5005 and 2683—less well in the last three. The motion in the Andromeda nebula and in 3623 is possibly more like that in the system of Saturn. It is greatest in nebula N.G.C. 4594. The rotation in this nebula has been verified at the Mt. Wilson Observatory.

Because of its bearing on the evolution of spiral nebulæ it is desirable to know the direction of rotation relative to the arms of the spirals. But this requires us to know which edge of the nebula is the nearer us, and we have not as yet by direct means succeeded in determining even the distance of the spiral nebulæ. However, indirect means, I believe, may here help us. It is well known that spiral nebulæ presenting their edge to us are commonly crossed by a dark band. This coincides with the equatorial plane and must belong to the nebula itself. It doubtless has its origin in dark or deficiently illuminated matter on our edge of the nebula, which absorbs (or occults) the light of the more brightly illumined inner part of the nebula. If now we imagine we view such a nebula from a point somewhat outside its plane the dark band would shift to the side and render the nebula unsymmetrical—the deficient edge being of course the one nearer us. This appears to be borne out by the nebulæ themselves for the inclined ones commonly show this typical dissymmetry. Thus we may infer their deficient side to be the one toward us.

When the result of this reasoning was applied to the above cases of rotation it turned out that the direction of rotation relative to the spiral arms was the same for all. (The nebula N.G.C. 4594 is unfortunately not useful in this as it is not inclined enough to show clearly the arms.) The central part—which is all of the nebulæ the spectrograms record—turns into the spiral arms as a spring turns in winding up. This agreement in direction of rotation furnishes a favorable check on the conclusion as to the nearer edge of the nebulæ, for of course we should expect that dynamically all spiral nebulæ rotate in the same direction with reference to the spiral arms. The character and rapidity of the rotation of the Virgo nebula N.G.C. 4594 suggests the possibility that it is expanding instead of contracting under the influence of gravitation, as we have been wont to think.

As noted before the majority of the nebulæ here discussed have positive velocities, and they are located in the region of sky near right ascension twelve hours which is rich in spiral nebulæ. In the opposite point of the sky some of the spiral nebulæ have negative velocities, *i. e.,* are approaching us; and it is to be expected that

when more are observed there, still others will be found to have approaching motion. It is unfortunate that the twenty-five observed objects are not more uniformly distributed over the sky as then the case could be better dealt with. It calls to mind the radial velocities of the stars which, in the sky about Orion, are receding and in the opposite part of the sky are approaching. This arrangement of the star velocities is due to the motion of the solar system relative to the stars. Professor Campbell at the Lick Observatory has accumulated a vast store of star velocities and has determined the motion of our sun with reference to those stars.

We may in like manner determine our motion relative to the spiral nebulæ, when sufficient material becomes available. A preliminary solution of the material at present available indicates that we are moving in the direction of right-ascension 22 hours and declination —22° with a velocity of about 700 km. While the number of nebulæ is small and their distribution poor this result may still be considered as indicating that we have some such drift through space. For us to have such motion and the stars not show it means that our whole stellar system moves and carries us with it. It has for a long time been suggested that the spiral nebulæ are stellar systems seen at great distances. This is the so-called "island universe" theory, which regards our stellar system and the Milky Way as a great spiral nebula which we see from within. This theory, it seems to me, gains favor in the present observations.

It is beyond the scope of this paper to discuss the different theories of the spiral nebulæ in the face of these and other observed facts. However, it seems that, if our solar system evolved from a nebula as we have long believed, that nebula was probably not one of the class of spirals here dealt with.

Our lamented Dr. Lowell was deeply interested in this investigation as he was in all matters touching upon the evolution of our solar system and I am indebted to him for his constant encouragement.

Lowell Observatory,
April, 1917.